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Experimental diagnostic challenges from the Bombardier Beetle

Andy McIntosh

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A Bombadier Beetle
(credit: Andy McIntosh)

The Bombardier Beetle

The Bombardier Beetle has the amazing ability to spray its predators with a toxic blast of steam.

Its extraordinary powers of defence have now inspired a new generation of technology.

Quentin Cooper

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BBC Look North, Sept 2007

'Beetle could be life saver - Leeds scientists believe the beetle's unique spraying technique could be a clue to saving lives.'
http://www.bbc.co.uk/mediaselector/check/player/nol/newsid_7000000/newsid_7001600?redirect=7001696.stm&news=1&bbwm=1&bbram=1&nbram=1&nbwm=1

Discovery Channel News, Oct 2007

29th Oct 2007 : http://dsc.discovery.com/news/2007/10/29/beetle-combustor.html

BBC Material World, Nov 2007

http://www.bbc.co.uk/radio4/science/thematerialworld_20071108.shtml

Der Spiegel, January 2008

Industrial Pharmacy, March 2008

Physics World, April 2008

http://physicsworld.com/cws/article/print/33577

Science Daily, April 2008

5th April 2008 :
http://www.sciencedaily.com/releases/2008/04/080401170543.htm

Scientific American, April 2008

3rd April 2008 60 second science
http://www.sciam.com/podcast/episode.cfm?id=14B29E60-974B-1718-3B3079783FEBA66E&sc=rss

MSNBC News, May 2008

'Beetle's toxic blasts trigger innovation, Scientists inspired by creature's unusual defense mechanism'
http://www.msnbc.msn.com/id/24637825/

The Naked scientist show, May 2009

"Bioengineering - Engineering Inspired By Nature"
31st May 2009
http://www.thenakedscientists.com/HTML/podcasts/show/2009.05.31/
http://www.thenakedscientists.com/HTML/content/interviews/interview/1139/
http://nakeddiscovery.com/downloads/split_podcasts/09.05.31/Naked_Scientists_Show_09.06.02_3954.mp3

Publications

Beheshti, N. & McIntosh, A.C., 'A Biomimetic study of the explosive discharge of the bombardier beetle', Int. Journal of Design & Nature. Vol. 1, No. 1, 61–69, 2007.

Beheshti, N. & McIntosh, A.C., 'The bombardier beetle and its use of a pressure relief valve system to deliver a periodic pulsed spray', Bioinsp. Biomim., No. 2, 57–64 2007.

McIntosh, A.C., Combustion, fire, and explosion in nature - some biomimetic possibilities. *Proc. IMechE, Part C: Journal of Mechanical Engineering Science*, **221**(C10), 1157–1164.

McIntosh, A.C. and Beheshti, N, “Insect inspiration”, Physics World (Inst of Physics), 21(4), 29-31, April 2008.

Applications being developed

B, SR, UK, BB/248700, 5/09/2007
IOP Publishing
Bioinsp. Biomim. 2 (2007) 1–8
Bioinspiration & Biomi
UNCORRECTED

The bombardier beetle and its use of a pressure relief valve system to deliver a periodic pulsed spray

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Abstract

In this paper the combustion chamber of the bombardier beetle is considered and recent findings are presented which demonstrate that certain parts of the anatomy are in fact inlet and outlet valves. In particular, the authors show that the intake and exhaust valve mechanism involves a repeated (pulsating) steam explosion, the principle of which was up till now unclear. New research here has now shown the characteristics of the ejections and the role of important valves. In this paper numerical simulations of the two-phase flow ejection are presented which demonstrate that the principle of cyclic water injection followed by water and steam decompression explosions is the fundamental mechanism used to create the repeated ejections

(Some figures in this article are in colour only in the electronic version)

Bombardier beetles are armed with a unique defence mechanism that squirts a hot spray of water/steam (figure 1) with additional noxious chemicals dissolved in the predators such as ants, frogs, birds, etc. This has attracted the curiosity of found that this spray

injected from tiny glands they exist in a crystallin hair-like material whic Aneshansley *et al* [4]

$C_6H_6O_2(aq) + H_2$

with three main dec

$C_6H_6O_2$

A BIOMIMETIC STUDY OF THE EXPLOSIVE DISCHARGE OF THE BOMBARDIER BEETLE

N. BEHESHTI & A.C. McINTOSH
Energy and Resources Research Institute, University of Leeds, Leeds, UK.

ABSTRACT

A biomimetic study of the bombardier beetle's explosive discharge apparatus was undertaken using numerical (CFD) modelling, first, of the beetle's combustion chamber, and then of a scaled-up combustion chamber with a view to its application to devices such as gas turbine relighters. The new findings about the existence of a pressure release valve at the beetle's combustion chamber exit yield a clearer understanding of the physics of the beetle's mass ejection mechanism. The scaled-up chamber (about 1 cm in length) is modelled by considering the chamber to be filled with liquid hexane which then undergoes vapour explosion through a pressure release valve at the exit. The ejection of vaporised fuel at high exit velocities has a number of applications, including gas turbine igniters.

Keywords: biomimetics, bombardier beetle, gas turbine relight, plasma injector, vapour explosion.

1 INTRODUCTION

A unique mechanism involving the discharge of hot products has been discovered to operate in certain types of Carabidae (ground beetles). These insects (of the family/genus Carabidae Brachinus) are found in South America, Africa and Asia (with a recent report of a *Brachinus crepitans* even appearing in the UK [1]). The defence mechanism of the brachinus beetle—commonly known as the bombardier beetle (Fig. 1)—is most unusual in that an aqueous combustible mixture of hydroquinone and hydrogen peroxide is catalysed by catalase and peroxidase which then heats the solution to boiling point. Evaporation then occurs within a few milliseconds and the mixture is ejected at 100°C on predators using a variable angle outlet nozzle which can be directed for pinpoint accuracy. The nozzle is so versatile that it can even be aimed forwards over the back of the beetle [2].

Figure 1: A bombardier beetle (brachina) ejecting its water–steam jet at 100°C forward from the tip

Feature: Spray technology

physicsworld.com

Insect inspiration

Insights gained from studying the remarkable defence mechanism of the bombardier beetle are helping to improve the spray technology used in drug-delivery devices, car engines and fire extinguishers, explain **Andy McIntosh** and **Novid Beheshti**

camera to film how the insect sprays. The resulting

Andy McIntosh is at the Energy and Resources Research Institute in the

Physics World, 21(4), April 2008, 29-31

- What we know
- Applications being developed
- Diagnostics
- Conclusions

- **What we know**
- **Applications being developed**
- **Diagnostics**
- **Conclusions**

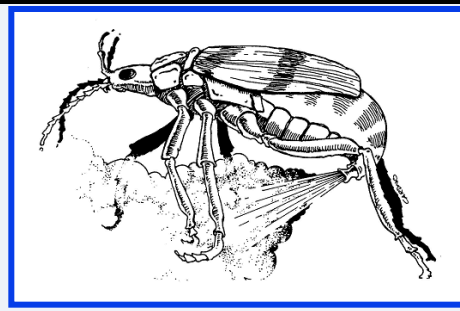
Bombardier Beetle

Bombardier Beetle

Bombardier Beetle

Physics of chamber and valve system

- Inlet valve
- Timing
- Pressure relief exit valve
- Repetitive pulse combustion



- An example of oscillatory combustion in nature
- A classic example of biomimetics
- - Combustion chamber design (valves) and nozzle
- - Chemistry

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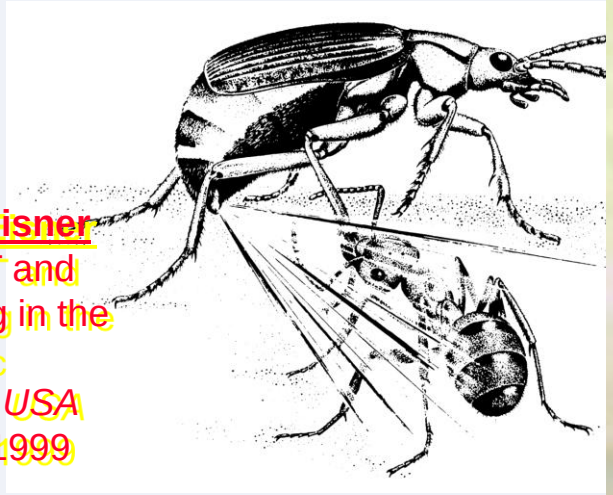
Experimental work by Eisner on Bombardier Beetle

Bombardier Beetle defence mechanism :



From work of Professor Tom Eisner of Cornell University : Eisner, T and Aneshansley, D. J, "Spray aiming in the bombardier beetle: Photographic evidence", *Proc. Natl. Acad. Sci. USA* Vol. 96, pp. 9705–9709, August 1999

Experimental work by Eisner on Bombardier Beetle

From the film ‘Alien Empire’, BBC

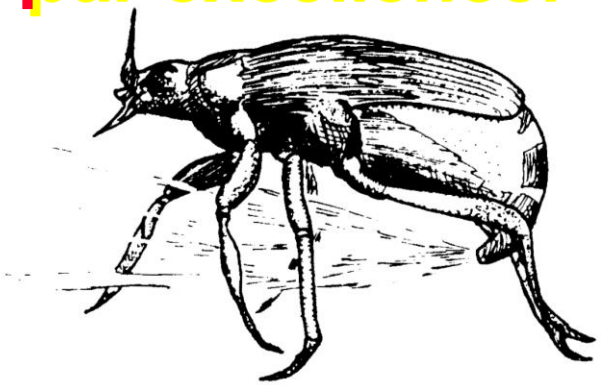
Experimental work by Eisner on Bombardier Beetle

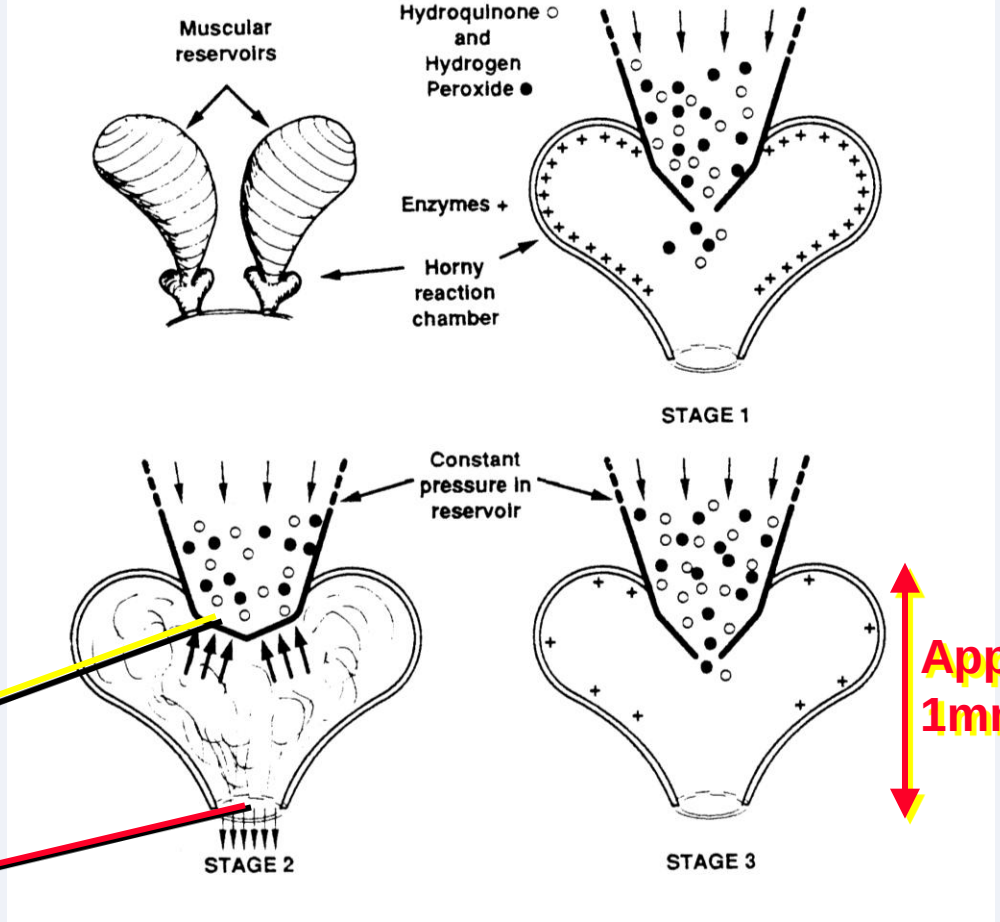
From the film ‘Secret Weapons’, BBC

Professor Tom Eisner, Cornell University

Experimental work by Eisner on Bombardier Beetle

Bombardier Beetle – Pulse combustion par excellence.





Fuel-inlet valve opened at low pressure, closed at high pressure.

Exhaust-outlet at high pressure.....

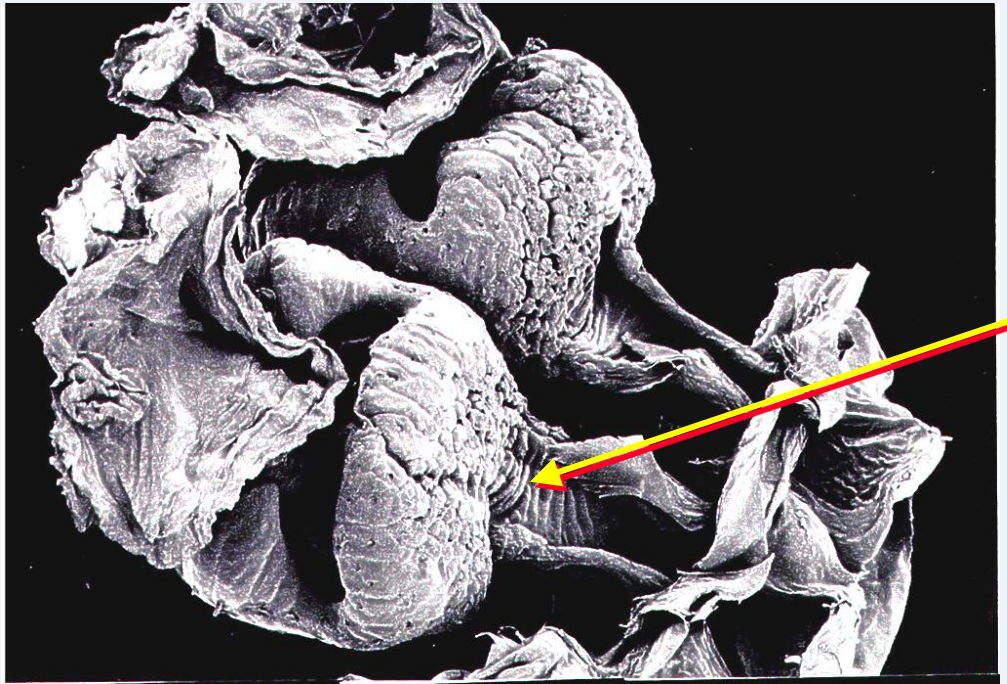
.....but also finding of a sophisticated pressure release valve at outlet

What we know

- **Exit valve observations**

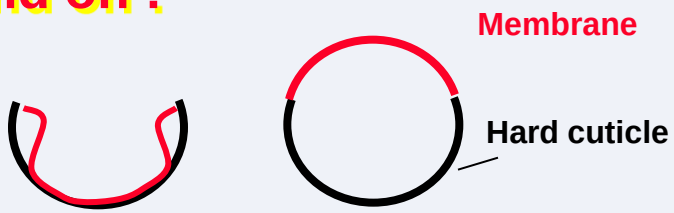
The exhaust valve – pressure release

- Major influence of the pressure release valve – this creates a ‘trigger pressure’ so that hot water now undergoes ‘cavitation’ explosion by pressure drop



The pressure release valve that it is thought controls the expulsion of the hot jet.

End on :



Closed **Open**

- Recap on what we know
- **Applications being developed**
- Diagnostics
- Conclusions

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3000 SWEDISH BIOMIMETICS®

The rig in action with large droplets and near maximum mass ejection .

Applications being developed

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Bombardier Beetle

Physics of chamber and valve system

- **Inlet valve**
- **Timing**
- **Pressure relief exit valve**
- **Temperature of chamber**
- **Repetitive pulse combustion**
- **Modality**
- **Droplet size**

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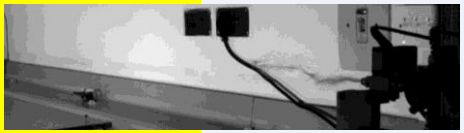
Applications to :

- Pharmaceutical - Nebuliser – (Aqueous and Organic)

1-10 μm

- Needless injector

~100 μm



- Fire extinguishers
- Fuel Injector

10-50 μm

- Aerosols

10-20 μm

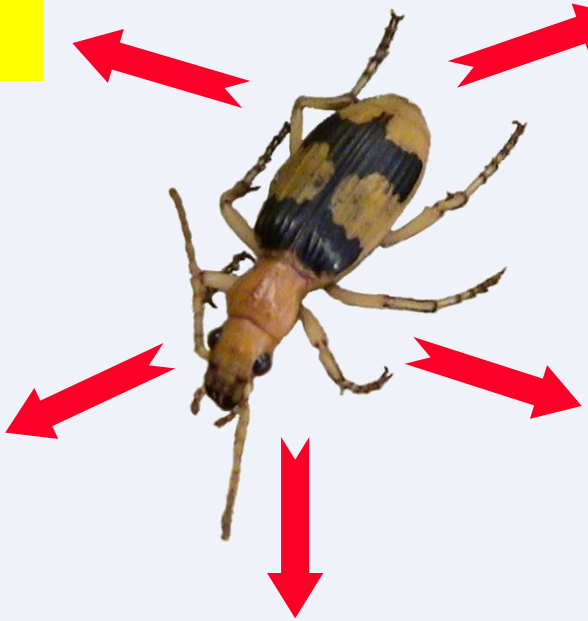
- Aeroponics

Applications being developed

Bombardier Beetle

Physics of chamber and valve system

Moveable Turret



Material Properties

Chemistry

Sensor System

Diagnostics needed

- Recap on what we know
- Applications being developed
- **Diagnostics**
- Conclusions

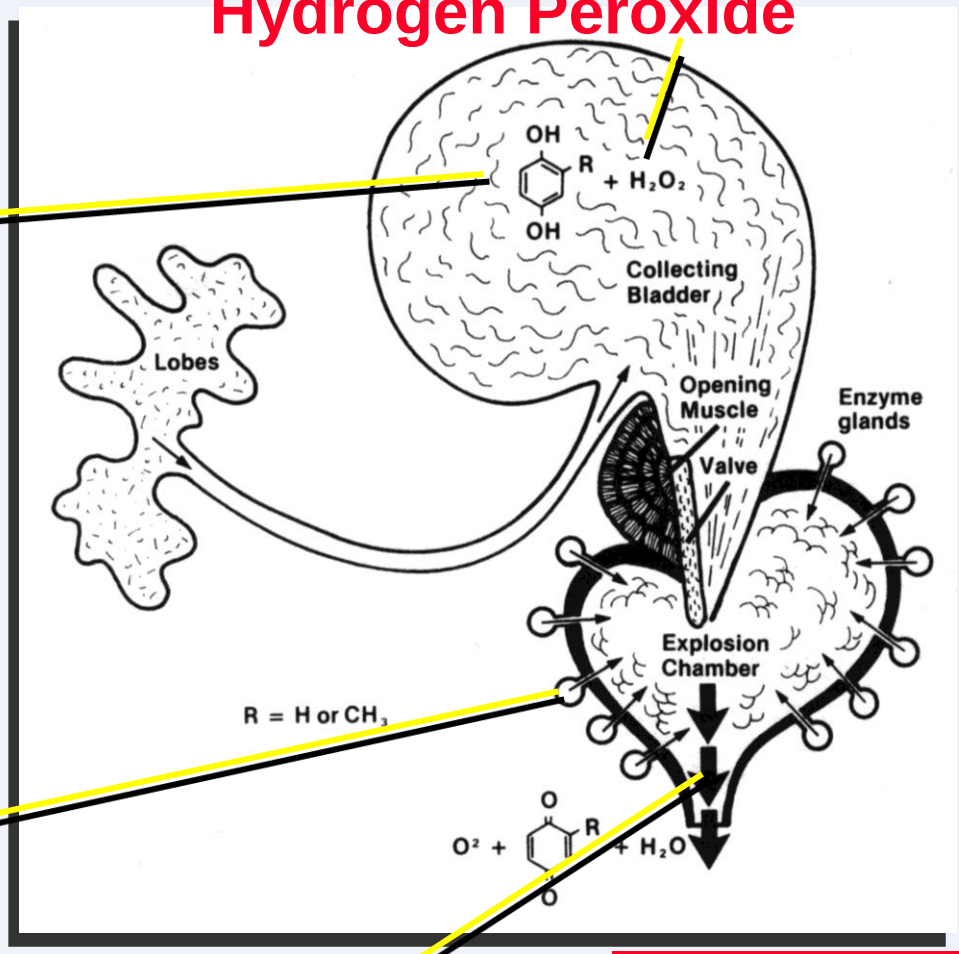
Experimental work by Eisner on Bombardier Beetle

Explosion Chamber of Bombardier Beetle

Hydrogen Peroxide

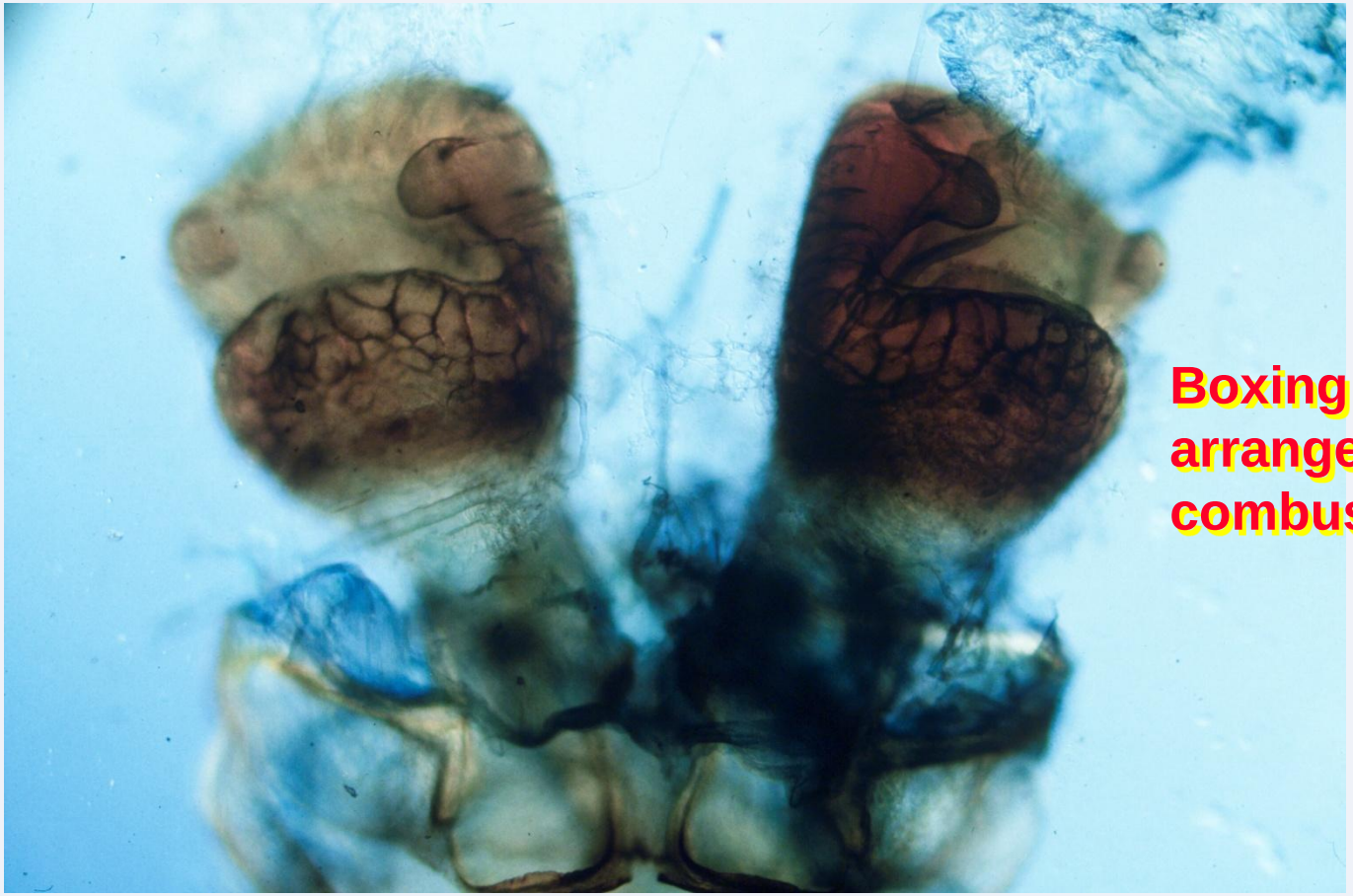
Hydroquinone

$$C_6H_6O_2 + H_2O_2 \rightarrow C_6H_4O_2 + 2H_2O$$



Enzymes – Catalase and Peroxidase

Catalytic combustion carefully timed



Boxing glove like arrangement of the combustion chambers.

Experimental work by Eisner on Bombardier Beetle

Chemical Reactions within Bombardier Beetle

Aqueous solution of reactants is stored in a reservoir, and is composed of hydroquinone $C_6H_6O_2$ at a concentration of 25% and hydrogen peroxide at concentration of 10% - Holoubek and Schildknecht

Salient steps

$$C_6H_6O_2(aq) \longrightarrow C_6H_4O_2(aq) + H_2(g) \qquad \Delta H_2 = +177{:}232\ Jmol^{-1}$$

$$H_2O_2(aq) \longrightarrow H_2O(l) + \tfrac{1}{2}O_2(g) \qquad \Delta H_3 = -94{:}5\ Jmol^{-1}$$

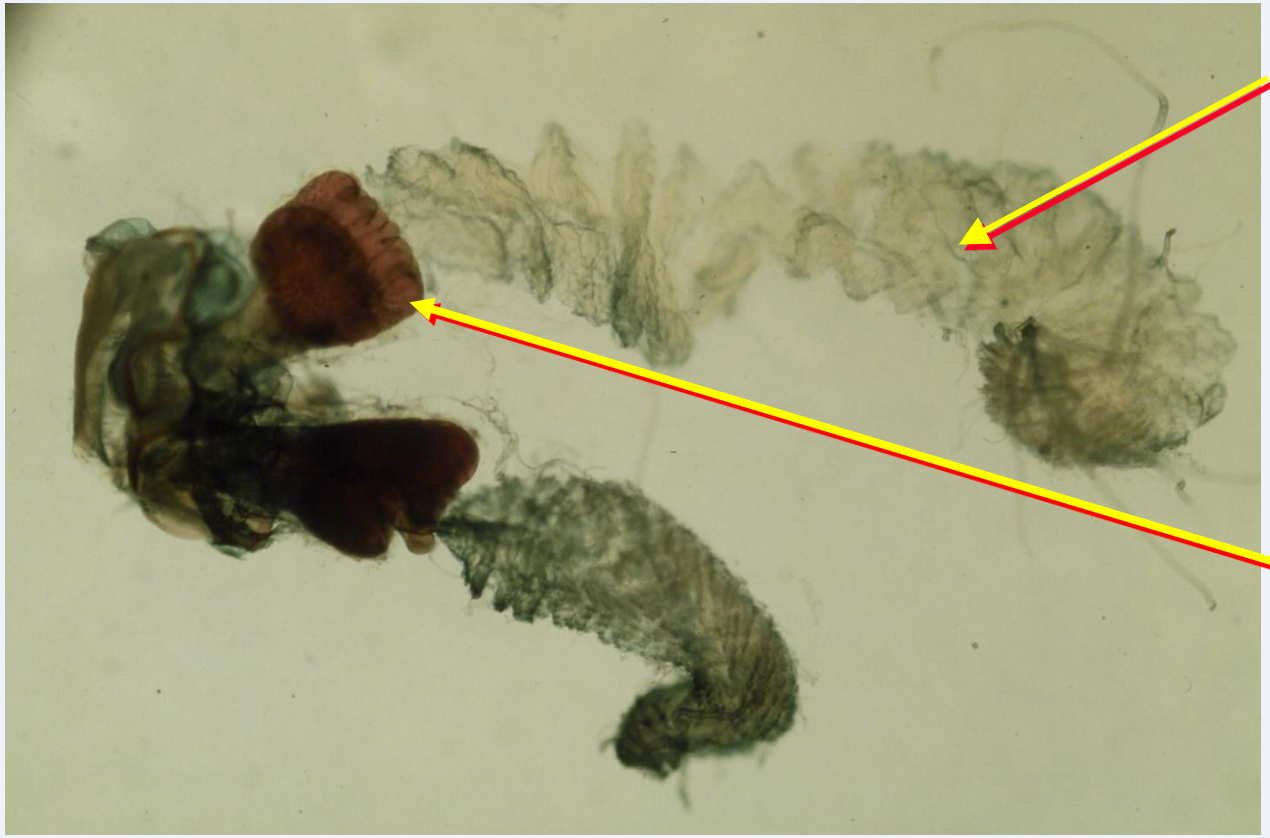
$$H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow H_2O(l) \qquad \Delta H_4 = -285{:}5\ J\ mol^{-1}$$

Overall Reaction

$$\Delta H_1 = -202.8\ Jmol^{-1}$$

$$C_6H_6O_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2O(l)$$

Total heat release for one kilogram of solution is then 794.2 kJ/kg solution



Extremely narrow diameter tubes in which it is believed the chemicals $C_6H_6O_2$ and H_2O_2 are made.

Combustion chamber.

Some questions :

1) Is it feasible to pass x-rays through the spray of the bombardier beetle whilst suspended in the process of exhausting (as Eisner dis in experiments at Cornell by using wax and a hook on the back of the beetle).

2) Is it possible that by analysing the dispersion of the x-rays, to then determine the temperature of the ejecting fluid?

3) Is there any way also of measuring the pressure and temperature within the chamber just before the outlet. Is this possible from such a small device (the combustion chamber is less than 1mm in length within the beetle which is approximately 1-2 cms. in total length)?

- Recap on what we know
- Applications being developed
- Diagnostics needed
- **Conclusions**

Conclusions

- The beetle has very many unique design features for inspiring biomimetics.

- Simulations and working models have been made, based on the valve system of the beetle

- Diagnostics are needed to establish the pressure and temperature in the chamber and just before the outlet valve

Thank you

Any questions and discussion?